# Radiation damage to materials for FAIR

*A. Belousov*[1], *G. Fehrenbacher*[1], *R. Lang*[1], *T. Radon*[1]
[1]GSI, Darmstadt, Germany

## Introduction

The accelerators of FAIR will allow to operate with 10-100 times higher intensities and up to 10 times higher energies than the present GSI accelerators. The prompt radiation will increase respectively. Thus it is very important to make estimations of dose rates in different areas of the facility and accordingly to select building materials considering their radiation hardness.

## Dose estimation

Monte Carlo FLUKA [1,2] calculations of dose rates were performed for every FAIR building considering different experiment scenarios. The highest dose rate corresponding to the "worst case" scenario was selected for each area. Knowing the material radiation hardness and the dose rate in the area, we can predict its lifetime and reliability.

## Assessment of radiation damage

Figure 1 shows damage versus accumulated dose for different types of materials. Expected accumulated doses after 20 years of FAIR operation are approximately from 10 Gy to $10^9$ Gy for different areas. The most sensitive materials to radiation are semiconductors. It is usually not recommended to put semiconductors in the vicinity of high radiation sources. Different polymers have moderate radiation resistance which varies over 5 orders of magnitude. Dose rates in some areas of FAIR will be sufficient to severely damage polymers in relatively short periods of time. Ceramics and especially metals have relatively high radiation resistance.

Most of the radiation hardness data present in the work was taken from CERN test results [3]. They contain descriptions of radiation damage effects to various materials and resulting scales showing how much radiation in Gy each material can withstand keeping its functionality. The scale of 3 conditions was normally used: mild damage, moderate damage and severe damage. Most of the materials were tested in one of the two usual ways: counting the number of 360° bends before break and measurements of the elongation at break. In some cases quantitative mechanical tests and visual tests were performed as well.

## Dependence of radiation damage on dose rate

Radiation damage to organic materials may depend not only on the overall dose but also on the irradiation dose rate. The amount of oxygen available by diffusion into the sample, in relation to the number of radiation-produced chemically reactive radicals, or chain scission sites, may strongly influence the amount of permanent damage to the material. Irradiations over longer periods are more problematic than short period exposures with the same dose values in some cases. Dose rate effects are dependent on the chemical structure of the material and sample shape. The amount of oxygen available is a function of the sample thickness, its permeability for gases and the amount of stabilizers added to the polymer control the oxidation damage.

CERN radiation hardness tests were usually performed at high dose rates ranging from $10^4$ to$10^6$ Gy/hour. Dose rates in FAIR will not exceed 10 Gy/hour. This huge difference makes dose rate effect very important in polymer lifetime estimation. Many polymers age about 10 times faster at low dose rates. Based on experimental studies [4] dose rate effects were taken into account for most of the polymer materials of interest.

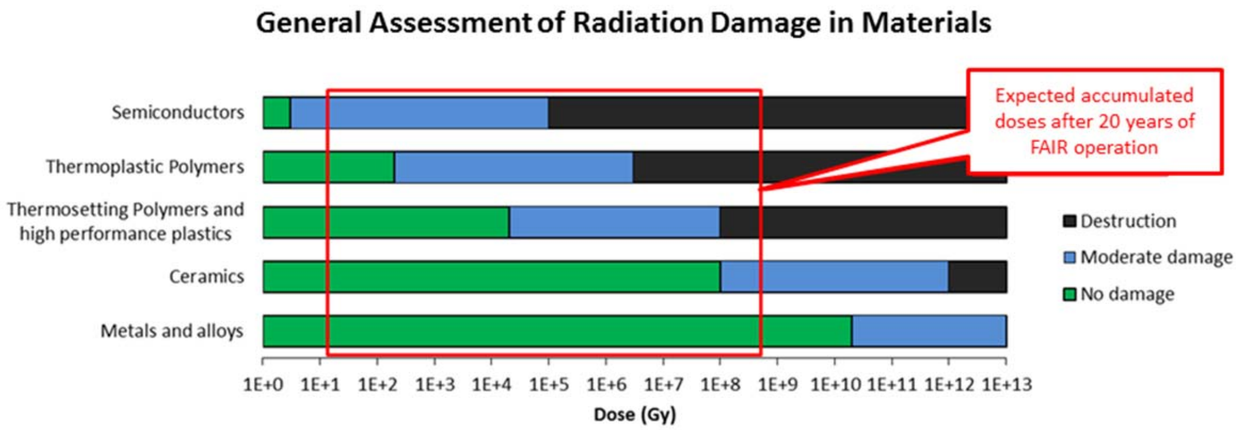


Figure 1: Radiation effects to materials and expected doses occuring in FAIR.


DOI:10.15120/GR-2015-1-MU-SAFETY-03

| **Building** | Geb 6 | Geb 7 | Geb 6a | Geb 6c | Geb 50 | Geb 4 | Geb 20 | Geb 18 | Geb 14 | T 103s |
|---|---|---|---|---|---|---|---|---|---|---|
| **µSv/h (beamline)** | 1.0E+05 | 5.0E+04 | 5.0E+06 | 5.0E+08 | 5.0E+07 | 3.0E+08 | 1.0E+08 | 5.0E+10 | 5.0E+06 | 5.0E+07 |
| **Operation days per year** | 200 | 180 | 200 | 180 | 162 | 250 | 180 | 180 | 200 | 250 |
| **Gy/year (beamline)** | 4.8E+01 | 2.2E+01 | 2.4E+03 | 2.2E+05 | 1.9E+04 | 1.8E+05 | 4.3E+04 | 2.2E+07 | 2.4E+03 | 3.0E+04 |
| Polyvinylchlorid | >1000 | >1000 | 42 | <1 | 5 | <1 | 2 | <1 | 42 | 3 |
| Polyethylene | >100 | >100 | 4 | <1 | <1 | <1 | <1 | <1 | 4 | <1 |
| Vernetztes Polyethylene | >1000 | >1000 | 29 | <1 | 4 | <1 | 2 | <1 | 29 | 2 |
| Geschirmtes Polyethylene | >1000 | >1000 | 29 | <1 | 4 | <1 | 2 | <1 | 29 | 2 |
| Polystyrol | >1000 | >1000 | >1000 | 19 | >100 | 22 | 93 | <1 | >1000 | >100 |
| Polyamid | >1000 | >1000 | >100 | 2 | 26 | 3 | 12 | <1 | >100 | 17 |
| Polypropylen | >100 | >100 | 2 | <1 | <1 | <1 | <1 | <1 | 2 | <1 |
| Polyurethan rubber | >1000 | >1000 | >100 | 1 | 15 | 2 | 7 | <1 | >100 | 10 |
| Polyurethan foam | >1000 | >1000 | >100 | 2 | 26 | 3 | 12 | <1 | >100 | 17 |
| Polyurethan resin | >1000 | >1000 | >1000 | 37 | >100 | 44 | >100 | <1 | >1000 | >100 |
| Polyester | >1000 | >1000 | 83 | <1 | 10 | 1 | 5 | <1 | 83 | 7 |
| Polyolefin | >1000 | >1000 | >100 | 1 | 17 | 2 | 7 | <1 | >100 | 11 |

Figure 2: Part of the table showing final results of the work. Table cells show material lifetime in years for each FAIR building. Green cells with lifetime above 20 years mean safe to use, yellow cells with lifetime between 10 and 20 years – questionable, red cells with lifetime below 10 years – not recommended to use.

## Results

Lifetimes of materials that are going to be used in FAIR construction were estimated considering specific radiation conditions in the accelerator environment. Results were based on CERN radiation test data. Moreover dose rate effect corrections were applied. Instructions and suggestions were given on whether or not a material is reliable to use in certain location. Results were given for about 50 materials and 20 FAIR buildings, 2 locations per building: hottest spot near beam line and near inner wall. Figure 2 shows a part of the table, where the lifetime in years is shown for several materials and locations. It is not recommended to use materials with less than 20 years lifetime, because replacement of damaged components may be complicated due to high activity values.

## References

[1] T.T. Böhlen, F. Cerutti, M.P.W. Chin, A. Fassò, A. Ferrari, P.G. Ortega, A. Mairani, P.R. Sala, G. Smirnov and V. Vlachoudis, “The FLUKA Code: Developments and Challenges for High Energy and Medical Applications”, Nuclear Data Sheets 120, 2014, 211-214

[2] A. Ferrari, P.R. Sala, A. Fasso, and J. Ranft, "FLUKA: a multi-particle transport code”, CERN-2005-10, 2005, INFN/TC_05/11, SLAC-R-773

[3] P. Beynel, P. Maier and H. Schönbacher, “Compilation of radiation damage test data, Part III: Materials used around high-energy accelerators”, 1982, CERN 82–10

[4] Hans Wilski, “The Radiation Induced Degradation of Polymers”, Radiat. Phys. Chem. Vol. 29, No. 1, 1987, p 1